Performance evaluation of a village-level solar dryer for tomato under Savanna Climate: Yola, Northeastern Nigeria

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Abstract: Solar energy is the most promising of the renewable energy sources in view of its apparent limitless potential. A small scale village–level solar dryer for tomato was developed under Yola weather at latitude 9°14′N and longitude 12°26′E using locally available materials and the performance was evaluated. The essence of the dryer was to achieve the effective method of tomato preservation and eliminate the drudgery and product deterioration associated with traditional methods of open sun drying of tomatoes. This is in view of alleviating the weather limitation experienced by farmers in crop drying especially for tomatoes. The solar dryer consists of tray, reflective walls and glass roof, a preheating air absorber plate, inner panels for removal of moisture and chimney through which air stream passes across the dryer. Evaluation of the dryer showed a raised temperature of about 47℃ attainable in the drying chamber. The dryer temperature and drying rate was found to be higher than the natural open sun drying method. The dryer was able to reduce moisture content of tomato from initial moisture content of 94% wet basis to 4% in three days with effective drying time of 24 h, efficiency of 64%, air mass flow rate of 0.025 kg s^{-1} and drying rate of 0.03906 kg h^{-1}. The results showed a considerable advantage of solar dryer over the traditional open sun drying method in term of drying rate and less risk for spoilage.

Keywords: solar dryer, moisture content, temperature, village-level, Savanna, Nigeria

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1 Introduction

Solar radiation is the most important energy resource to human which can supplement many farm energy requirements (Adejumo and Bamgboye, 2004). Using solar energy dry crops and grain is one of the oldest and most widely used applications. The simplest and least expensive technique is to allow crops to dry naturally in the field, or to spread grains and fruits out in the sun after harvesting. These crops are damaged by birds, rodents, wind and rain and contamination by dust and dirt which further deteriorate during storage and constitute a great lost (Singh, 1994, Adejumo and Bamgboye, 2004; Nehemiah, 2008). Singh (1994) stated that about 30% of crops are lost in the developing countries using traditional methods. These losses are due to slow drying rate of the traditional open sun drying, which takes about three days to dry a slice of tomato at the beginning of dry season and eight days to dry at the peak of hamattan.

In Nigeria sun drying of agricultural product is the most popular and wide spread drying method and a very important category of rural industrial activity because of the abundance of sun shine all year round. It is in the high solar radiant belt of the world and receives an annual average of about 3.5 kW hm^{-2} d^{-1} in the coastal latitudes and about 7.0 kWhm-^{2} d^{-1} in the far north of Nigeria (Okwonkwo et al, 1999). Itodo et al (2002) stated that in Nigeria especially North-eastern part of Nigeria, farmers were still using the common traditional practice of open sun drying method for drying crops because electricity supply is not steady and cost of fossil fuel was

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very high. Solar dryers with typically attained temperature of up to 60-70℃ are suitable for drying a variety of agricultural products (Sambo, 1995, Adejumo and Bamgboye, 2004).

Itodo, et al, (2002) reported that engineered solar dryers have overcome the limitations of the open air sun drying method. In line with this, Awechie (1982), designed and constructed a solar box and obtained a temperature of 180℃ for drying crops, Troager (1992) constructed a solar permanent drying system consisting of a flate-plate collector made from corrugated galvanized iron sheets and achieved 50℃ chamber temperature. Itodo et al, (2002) developed an indirect passive dryer with rock bed and achieved collector and system drying efficiencies of 12% and 10% respectively, Itodo et al, (2004) evaluated the performance of a direct active dryer using cassava marsh with centrifugal fan forcing the air through the dryer. The collection, system and pick-up efficiencies were 46%, 9% and 29% respectively with a drying rate of 1.60 kg d^{-1}. Itodo and Fulani (2004) developed a passive solar dryer with an air preheated unit in order to improve the efficiencies of collection, system and pickup. The sun-drying rate was 1.60 kg d^{-1}, collection, system and pickup efficiencies were 85%, 7% and 14% respectively under Makurdi climate.

Sambo (1995) reported that the level of development and application of solar dryers in Nigeria today would lead to tremendous benefits in the way of agricultural output if solar energy is harnessed for on -farm utilizations. According to Itodo and Fulani (2004) one technology of solar dryer cannot suffice for all locations because of the variability of solar parameters. This makes it important to develop technologies for optimum performance for various locations. However, in most location, most crops are harvested when the outdoor air conditions are not suitable for natural air drying and crops have relatively short time of spoilage unless the moisture is removed. It therefore becomes necessary to heat the air before providing a high drying potential. Pembi (2000) developed a small scale solar dryer with the aim of achieving effective method of tomato preservation and eliminating the drudgery and product deterioration associated with traditional methods of open sun drying of tomatoes. The full performance in terms of drying rate, collection system and absorber temperatures were evaluated.

2 Materials and methods

2.1 Description of the solar dryer

Figure 1, Figure 2 and Figure 3 shows the general features of the solar dryer. The dryer consists of a chimney (8) of 73 mm in diameter and 310 mm in height located on the top of the dryer to discharge heated air and moisture from the products into the atmosphere; a plain glass (10) with an area of 600 mm × 410 mm served as solar collector to permit in only sun radiation. It is made of a silicate glass of 3 mm in thickness. A tray window opening (11) is provided behind the dryer for loading and unloading the dryer. The wall of the drying box (6) where the drying tray (13) is located is made of wood of 50 mm in thickness and insulated with sawdust to serve as insulator for the heated air in the dryer. Air vent (12) is provided on the lower front side with a total area of 400 mm × 100 mm for easy passage of air into the dryer. The vent is covered with mosquitor net to prevent insects into the dryer. The alluminum absorber plate (5) of 30 mm in thickness measuring 600 mm × 400 mm was provided to absorb heat. The frame of the dryer (6) is made of wood of 50 mm in thickness. The legs of the frame (1) are made of angle iron and tilted at an angle of 9.14^0 to the horizontal to give an inclination equal to the latitude of Yola (9.14^0). The inside of the dryer was painted black to enhance the absorbtion of sunlight and reduced emission of infrared radiation, while the outside was painted with light grey colour to reflect solar radiator. The dryer has an overall dimensions of 1,280 mm × 540 mm × 1,280 mm in lenght, width and height respectively.

2.2 Operation

The dryer is placed in the open space free from shade throughout the day. One kilogram of tomatoes in weight is prepared and the initial moisture content of 94% is sprayed on the dryer tray. Sun radiation falling on the glass is being absorbed by the collector plate painted black and transmitted into the drying chamber through the inlet window by natural air blowing. This removes the moisture given out in the drying process.

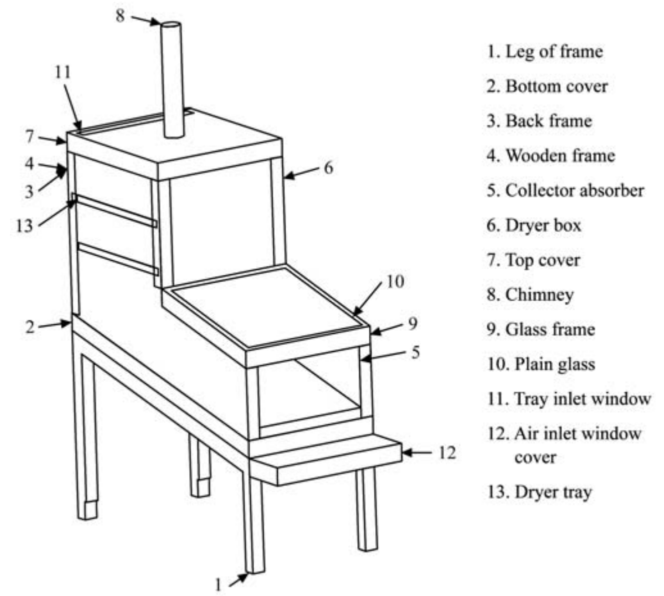

Figure 1 Isometric view of the solar dryer

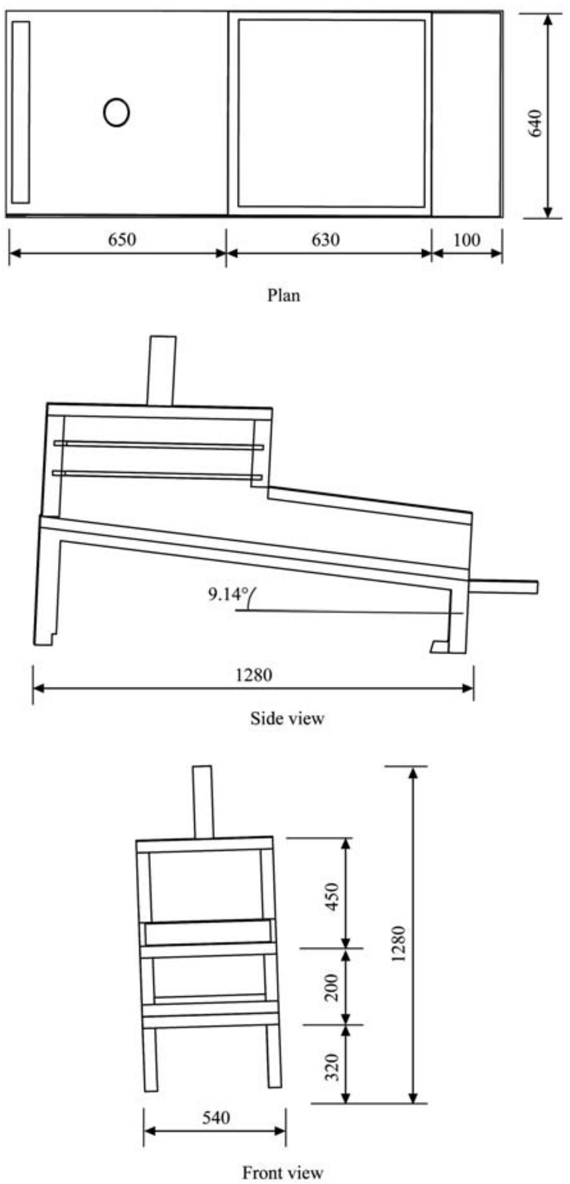

Figure 2 Orthographic view of the solar dryer

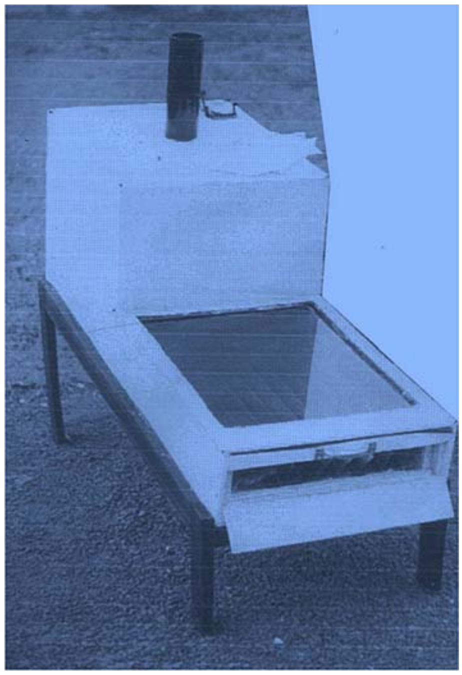

Figure 3 Constructed solar dryer

3 Performance evaluation

The performance of the solar dryer was carried out first when drying chamber was empty to study the maximum obtainable temperature per day for three days in October 2011. Secondly a known mass of tomato slices of 1.6 kg with initial moisture content of 95% were spread on the dryer tray and equally on the control open air. Temperature of the sample was taken for moisture content determination every two hours for ten hours per day for three days.

The solar dryer was tested under a period of low temperature from 23 to 35℃ and humidity period of 60-88%. The prevailing physical conditions, temperature, and relative humidity of the dryer and ambient conditions were monitored using thermometers and relative humidity sensors located at strategic points within the solar collectors/heat storage unit and drying chamber. The dryer was filled with tomato slices of 5mm in thickness with initial moisture content of 95%. A similar quantity and size of tomatoes was spread outside using the traditional open-air sun drying method as a control. The moisture content of the sample was determined from weights of samples before and after drying by an oven at 80% wet basis. The loss on product weight is assumed to be equivalent to product moisture loss during drying. The dryer's performance parameters were evaluated from the testing results using Equation (1), Equation (2), Equation (3), Equation (4) and Equation (5) below.

Amount of moisture to be removed; $$W_w = \frac{W_g(M_i - M_f)}{(100 - M_f)} \quad (1)$$

Tomato drying rate; $$W_{dr} = \frac{W_w}{T_d} \quad (2)$$

Useful heat gain by the dryer; $$Q_u = A_c G C_p (T_0 - T_1) \quad (3)$$

Heat gain by the absorber plate; $$Q_g = Q\tau \quad (4)$$

Dryer efficiency; $$\eta = \frac{Q_u}{Q_g} \times 100 \quad (5)$$

where, W_w = Amount of moisture removed, kg; W_g = Initial mass of wet tomato to be dried, kg; M_i = Initial moisture content, %; M_f = Final moisture content, %; W_{dr} = Average drying rate, kg h^{-1}; T_d = Total drying time, h; Qu = Useful heat gain by the dryer; A_c = Area of the collector, m^2; G = Mass flowrate of air in the dryer, kg s^{-1}; C_p = Specific capacity of air at mean temperature; T_0 = Collector outlet temperature, ℃; T_1 = Collector inlet air temperature, ℃; Q_g = Heat gain by the absorber plate; Q = Radiation transmitted through the tilted collector, kW m^{-2}; τ = Transmissivity of the glass; η = Dryer efficiency, %.

4 Results and discussion

The results of the test carried out with the solar dryer are given in Table 1 and Table 2. The result of the performance evaluation shows that under all-weather condition, the solar dryer performs better than the natural sun-drying method. Figure 4 shows the obtained temperature profile for empty chamber similar to those obtained by Igbeka (1980); Mokofe et al, (1999); Adejumo and Bamgboye (2004) with high average temperature of about 48℃. Table 1 shows that a maximum temperature of about 50℃ is obtainable compared to open air tray of 38℃ and the temperature varied with the time of the day. The temperature obtained in this work was higher than the temperature range of 30-45℃ for drying foods and fruits obtained by Kordylas (1989) and in agreement with Awochie (1982). The open air tray is slower in drying than that of the solar dryer, which was obtained by Troager (1983), Igbeka, (1990), Okwonkwo and Okoye (2004) and Adejumo and Bamgboye (2004).

Table 2 shows that the final product moisture at the end of the three days is lower in the solar dryer than that in the open air. This is because of the raised chamber temperature and relative humidity of the open air. The dryer was found to dry the products to safe storage moisture content of 4% for long period in three days drying which is not obtainable in the open air sun drying. Despite the fact that the dryer evaluation was carried out in October under low temperature of 22-35℃ and a higher mean relative humidity period of 80–87%, which covers a period of crop harvest and processing, the dryer attained a higher temperature range of 30-50℃. The solar dryer has a drying rate of 0.03906 kg h^{-1}, drying efficiency of 64% with air mass flowrate of 0.025 kg s^{-1}. This temperature range is ideal for drying foods and crops which agreed with the work of Ofi, (1982).

Table 1 Empty chamber and open air temperature

Time of the day	Day 1		Day 2		Day 3		Average	
	Dryer	Open air	Dryer	Open air	Dryer	Open air	Dryer	Open air
08.00	22	22	23	23	28	26	25.5	23.67
09.00	28	24	32	28.5	39	30	33	27.50
10.00	34	28	37	29	27	29	32.67	28.67
11.00	43	33	38	31	41	32	40.67	32
12.00	43	32	43	33	45	36	43.67	33.67
13.00	40	30	40	31	47	37.5	42.33	32.83
14.00	47	30	50	38	47	37.5	48	35.17
15.00	48	29	45	36	44	35	45.67	33.33
16.00	45	38.5	44	35	37	29.7	42	31
17.00	37	28	38	30	36	28	37	28.67
18.00	35	27	36	28	35	29	35.33	28

Table 2 Solar dryer performance continues drying at 10 h d^{-1}

Time	Weight of sample/g		Moisture content (WB)/%	
	Solar dryer	Open sun	Solar dryer	Open sun
09.00	1000	1000	94	94
11.00	850	920	79.9	86.5
13.00	750	680	70.5	80
08.00	550	640	51	60.3
10.00	530	64	49	57.3
12.00	325	550	30.6	51.7
14.00	250	480	23.5	45
16.00	225	365	21.2	34
18.00	205	345	19.3	32.4
08.00	125	325	11.8	30.6
10.00	123	295	11.6	27.7
12.00	100	250	10.8	23.5
14.00	75	220	7.0	21.0
16.00	50	220	4.7	20.7
6pm	43	219	4.0	19.7

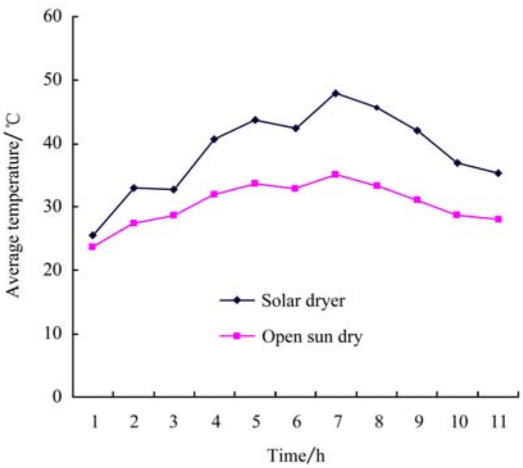

Figure 4 Temperature curves for solar dryer empty chamber and open air

The greatest moisture reduction was observed to have occurred between 10.00 to 14.00 daily when the solar intensity and collector drying air temperature was the greatest The dryer and ambient relative humility were ranged between 11.5-45% and 80-87% respectively.

The samples dried in the solar dryer were clean and of high quality with no contamination through dust or insect and did not change color while those under open air sun drying showed changes in color indicating signs of deterioration in quality(Gomex,1982). Tables 3 and 4 shows a statistical analysis (paired t-test) for comparing the population means of Tables 1 and Table 2 at 0.05% level. The results shows a significant difference. It was concluded that the solar dryer increases the drying rate significantly.

Table 3 Statistical analysis (paired t-test) for comparing the population means of tables 1 at 0.05% level

Source of variation	df	Mean value (d)	SE(d)	T
Between treatment	10	8.30	1.034	8.24*

Note: * t is significant.

Table 4 Statistical analysis (paired t-test) for comparing the population means of tables 2 at 0.05% level

Source of variation	df	Mean value (d)	SE(d)	T
Between treatment	13	13.96	1.228	11.37*

Note: * t is significant.

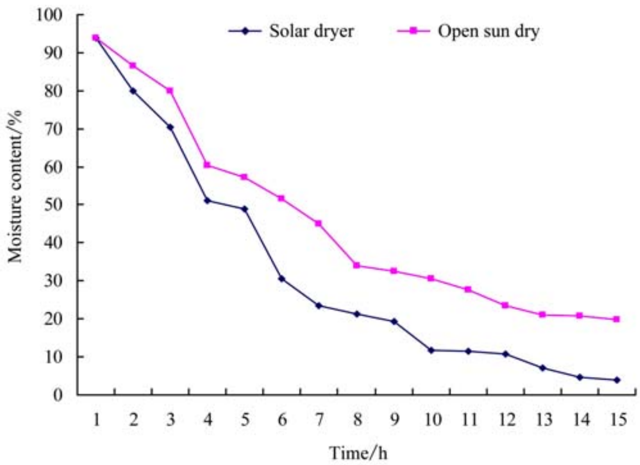

Figure 5 Drying curves for tomato

5 Conclusion

Performance evaluation of small scale solar dryer was carried out under Yola climate. The result of the performance evaluation showed that the solar dryer dries faster than the natural open sun drying method with drying chamber temperature of up to 40℃. The tomato were dried from initial moisture content of 95% in three days of drying process to a long term storage moisture content of 4% while it took about five days for the open air sun drying sample to attain a moisture content of 15% from the same initial moisture content of 95%. The dryer has a capacity of about seven kg, the highest attainable temperature of 50℃. This shows that solar energy can be harnessed and used to dry tomatoes especially during crop harvest and during poor weather. The drying efficiency was found to be 64%.

Tomatoes dried under the solar dryer gives faster drying process, high quality products and over 50% time savings than open air sun drying.

It was recommended that a means for thermal storage and installation of low pressured solar powered fan at the inlet section be investigated so as to achieve a faster drying rate.

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